These differences and contrasts on the one hand perpetually disturb the orderly arrangement of air densities and pressures demanded by gravity. The latter, on the other hand, as perpetually and continuously sets portions of the air in motion, in order to establish and maintain a state of equilibrium, which, however, is never attained. We must clearly recognize that *the ceaseless complex changes in and motions of our atmosphere* represent in fact the only state of equilibrium possible between gravity on the one hand and solar heating of the earth on the other.

The disposition on the part of some to attribute important phenomena of terrestrial weather to minor solar activities is believed to be a mistake. It is in fact believed that apparent changes in solar activity, especially of the thermal character, are in reality altogether of terrestrial origin and that the imaginary correlations between terrestrial and solar activities are really the simple relations between atmospheric phenomena at one point and possibly those at another on the earth itself. It is most important that these major problems of cause-and-effect relation between solar and terrestrial activities should be observed, not only with the greatest possible accuracy but that the observational data themselves should be thoroughly analyzed and discussed, first, to establish the magnitude of the errors of the observation, and second, to determine the possible relations between solar and atmospheric effects.

Seemingly the greatest need in meteorology is that of a master mind to direct itself comprehendingly and intensively to the great problems which the science still presents.

SOME OF THE CHIEF PROBLEMS IN TERRESTRIAL MAGNETISM AND ELECTRICITY

BY LOUIS A. BAUER

1. *Analysis of the Earth's General Magnetic Field:* The early completion of the general magnetic survey of the globe, as undertaken by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington and coöperating countries, will afford the necessary data for the investigation of some of the so-called "greater problems of the earth's magnetism." One of these is the determination of the various systems of magnetic and electric forces which together make up the total terrestrial magnetic field as observed at the earth's surface. It is known from previous analyses that the earth's magnetic field consists of an internal system of forces, which constitutes by far the major portion; secondly, an external system, supposedly to be ascribed to electric currents circulating in the earth's atmosphere; and, thirdly, a system possibly such as that of vertical electric currents which pass from the atmosphere into the earth and vice versa. The definite settlement of the question as to the existence of the third system is regarded by Sir Arthur Schuster as one

of the chief outstanding problems in terrestrial magnetism. This problem involves the question whether or not the magnetic forces of the earth can be entirely referred to a potential. If not, then the question arises as to the existence of vertical electric currents, which will be of interest both to students of the earth's magnetism and of the earth's electricity, using the latter term in its most general sense so as to include electric phenomena arising from systems both below and above the earth's surface. The ocean work of the Department of Terrestrial Magnetism has been arranged with the special view of obtaining the requisite data for the solution of this interesting question. But for the war all the necessary data and the results of their discussion would be available now.

2. *Analysis of Continental and Regional Magnetic Fields:* The detailed magnetic survey of the United States—the largest land area over which magnetic surveys with the requisite accuracy and detail have been made—affords further opportunity for the investigation of the problems referred to in the previous paragraph, at least so far as the investigation of those problems can be undertaken for a limited region of the globe. In the respect that the magnetic constants of the earth's general field depend in a very large measure upon the area embraced in the investigations, problems of terrestrial magnetism differ fundamentally from those of geodesy. Concerning this point, a preliminary study was made by the writer in connection with a brief discussion of "Some Results of the Magnetic Survey of the United States" printed in *Science*, May 22, 1908, (812–816).

It was found that the magnetic forces observed at any given point in the United States are the resultant effects of (1) a general or terrestrial magnetic field arising from the general magnetic condition of the earth, (2) a general, terrestrial disturbing cause which distorts the general magnetic condition of the earth at the place of observation, related possibly in some manner to the rotation of the earth, (3) a continental disturbing effect, arising largely from that portion of the North American continent above the general ocean bed, (4) a regional disturbance caused by low-lying magnetized masses or earth-currents covering a certain region, and (5), a local disturbance to be referred to magnetized masses or currents in the immediate vicinity.

A mathematical formula of limited spherical harmonic terms based upon the entire earth cannot, of course, include also disturbances of such restricted areas as are embraced under Nos. 4 and 5, namely, regional and local disturbances, but it appears that such a formula cannot adequately represent even the *continental* effects. In the spherical-harmonic formulae the terms of the various orders advance and recur by trigonometric functions of multiples of the longitude and the latitude. Thus a term involving six times the longitude is supposed to continue around the earth six times in unaltered manner. However, such a term arising, for example, from the North American continental shelf, which in the

United States has a width in longitude of about 60°, would not continue around the earth but would in all probability die out before the European or the Asiatic continent is reached. In brief, the higher harmonic terms of the mathematical formula introduced by Gauss and based on the potential theory, could at the best but simulate or "counterfeit" the facts of nature and not represent the actual truth.

Thus the question arises how far it is really worth while to proceed in the establishment of such a theoretical formula. Although the mathematical expressions may be extended so as to include forty-eight or more unknowns, it has been found that the computed results, magnetic declinations, for example, depart so much from the actual observed results—several degrees—that they could not be used even for purely practical purposes such as those of the surveyor and the navigator. The conclusion therefore reached was that it may be found sufficient for many purposes to restrict the theoretical formulae to a certain finite number of terms involving a limited number of unknowns which represent, from a physical standpoint, the chief and principal facts of the magnetic condition of the earth, as resulting, for example, from system (1) mentioned above, or perhaps better, systems (1) and (2). The magnetic field represented by this limited expression might be called the normal, or reference field, just as the geodesist, who restricts the constants to be determined for the figure of the earth to two or three, calls his adopted figure, the "spheroid of reference." Residuals from the magnetic field of reference would then receive separate or special treatment in accordance with their extent and their character.

Respecting the existence of possible vertical currents, the preliminary analysis of the data of the magnetic survey of the United States indicated a definite system, related in some manner to the general atmospheric circulation and with an average current strength of about $^1/_{30}$ ampere per square kilometer, just as the writer had found in his previous investigations pertaining to the entire earth.[1] The additional data acquired in the United States since the preliminary analysis, will make possible a more complete investigation of this important matter. Of special interest in this connection will be found the quotations regarding Dr. Wilson's investigations (see paragraph 4).

We see then that the data obtained by the United States Coast and Geodetic Survey in the prosecution of the magnetic survey of the United States afford opportunities for interesting and fruitful research of various kinds. There may be mentioned, for example, the correlation between magnetically disturbed areas and geological formations or local deviations of the plumb-line, in which Section *a* (Geodesy) is also interested. Possibly also the data obtained in the United States may throw some light ultimately upon the problem as to the variation of the magnetic elements with altitude, and upon the question as to the effect of local or regional disturbances upon the secular changes of the earth's magnetism.

3. *Effect of Altitude upon the Earth's Magnetic and Electric Elements:* One of the important problems, both from a practical and a theoretical standpoint, is that of making magnetic and electric observations in the upper regions of the atmosphere. A number of investigations of extreme interest fall under this head. How the magnetic data for the United States may contribute towards the solution of some of the problems has already been stated. The preliminary analysis mentioned gave some indication of dependence of vertical-intensity residuals upon altitude. A joint investigation by the Department of Terrestrial Magnetism and the United States Coast and Geodetic Survey was made of the mountainous region about Pike's Peak, Colorado, directly after the eclipse observations of June 8, 1918. The magnetic stations ranged in altitude from about 6,000 feet to 14,000 feet. Whether any definite result may be derived from such mountain observations as to rate of variation of magnetic elements with altitude, in view of the minuteness of the probable variations, depends upon the successful elimination of the local disturbances caused by magnetic rocks. It was found that the region investigated was not wholly free from such disturbances. It will be necessary for the solution of the problem to devise instruments of sufficient sensitiveness and stability to make possible magnetic observations of the required accuracy in air ships. To show the necessity of altitude magnetic observations, it will suffice to say that an infinite number of distributions of magnetic and electric systems within the earth may be found which will satisfy observations made simply on the surface of the earth.

Complete atmospheric-electric and radioactive observations in the upper regions of the atmosphere are of fundamental importance to the problems of the earth's electric field: of its maintenance, and of its variations. It is very much to be hoped that such observations may soon be systematically carried out in the United States.

4. *Variations in the Earth's Magnetic and Electric Phenomena:* The study of these variations opens up a wide field of research of interest not only to the Section of Terrestrial Magnetism and Electricity but also to other sections of the American Geophysical Union. In investigations as to a correspondence between manifestations of the earth's magnetic, or electric, activity with the Sun's activity, one of the fundamental questions is what to take as the complete measure of activity, either for the earth or for the sun. This question also enters into certain meteorological investigations. In this way, and as appears later, some of the problems of Section *d* (Terrestrial Magnetism and Electricity) also touch upon some of those of Section *c* (Meteorology). The following quotations from the Annual Report of the University of Cambridge for 1919, relating to investigations made by Dr. C. T. R. Wilson at the Solar Physics Observatory, are of particular interest here:

"The results obtained in these investigations have suggested a theory, which both accounts for many of the more important phenomena of thunderstorms, and relates them to those of fine-weather atmospheric electricity and terrestrial magnetism....

"The order of magnitude of the currents in thunderstorms, as indicated by the results of observations of lightning discharges, is such as to suggest the possibility of correlating the phenomena of atmospheric electricity with those of terrestrial magnetism."

5. *Magnetic Storms, Polar Lights and Earth Currents:* Many problems of interest to several sciences come under this head. The various pronounced manifestations of solar activity and terrestrial magnetic and electric activity during the past month, especially March 22–23, have called renewed attention to these problems. The magnetic disturbance of March 22–23 was world-wide and was one of the severest recorded. On the evening of March 22 one of the most remarkable displays of the Aurora Borealis was witnessed at Washington and at points in even lower latitudes; at a corresponding time there was a fine display of the Aurora Australis at the magnetic observatory of the Department of Terrestrial Magnetism at Watheroo, Western Australia. During the magnetic disturbances and auroral displays the generated earth-currents caused interruptions on cable and telegraph lines. The sun-spot activity during this period was of a very marked and interesting character. Dr. Abbot reported that the solar constant, as observed by the Smithsonian Institution party at Calama, Chile, on March 23, had reached the low value of 1.866, whereas from January 1 to March 22 it had varied from 1.93 to 2.00; on March 24, the value was 1.905, and thereafter it went up again. This case illustrates well the joint interest of various sciences.

The general effect of magnetic disturbances is to diminish for a time the intensity of magnetization of the earth's field, in severe cases as much as ten percent. It took about three months after the severest magnetic storm on record, the one of September 26, 1909, before the earth's magnetic intensity had returned to its approximate normal value. An interesting theory[2] of magnetic storms has recently been advanced by Prof. F. A. Lindemann, director of the Department of Physics at the Univeristy of Oxford. To overcome some of the difficulties of Dr. Chapman's theory[3] of a stream of charged particles, Lindemann suggests the alternative of clouds of ionized gas ejected from the Sun and driven away by light-pressure. Such a cloud would be completely ionized, and therefore invisible; it would be kept generally together because it contains both positive and negative ions; and yet it would expand sufficiently to satisfy observed facts about the duration of magnetic storms as the earth passes through the cloud—in our upper atmosphere the ions would recombine and cause the storm. The theory is worked out quantitatively and found to satisfy known facts.

6. *Magnetic and Electric Observations During Solar Eclipses:* Intensive observations under this head have been made, especially since the total

solar eclipse of May 28, 1900, which occurred in the southeastern part of the United States, the writer being then in charge of the magnetic work of the Coast and Geodetic Survey. Nearly every prominent solar eclipse since then has been taken advantage of and coöperative observations over the entire globe have generally been made in accordance with a program outlined by the Department of Terrestrial Magnetism. Briefly stated, the general result has been that an appreciable magnetic effect, though of a minute order, is recorded during the period of a solar eclipse, similar in character to the variation experienced by the earth during a solar day, and differing from it only in magnitude. It is believed that the detection and study of an eclipse magnetic effect will be of great importance to theories of the earth's magnetic field and of its variations.

During the famous solar eclipse of May 29, 1919, the Department of Terrestrial Magnetism had two expeditions in the belt of totality: at Sobral, Brazil, under the charge of D. M. Wise, assisted by A. Thomson; and at Cape Palmas, Liberia, under the writer's charge, assisted by H. F. Johnston. At Cape Palmas there was experienced the longest totality (6 minutes, 33 seconds) enjoyed by any of the eclipse parties. The geophysical observations at the two stations will have an important bearing upon the complete interpretation of the light deflections observed by the British expeditions stationed at Sobral, Brazil, and the Île of Principe.[4]

Besides the magnetic results, interesting electric results were also obtained at Sobral, which, briefly stated, are:[5]

a. The potential gradient showed a well-formed minimum beginning with totality and extending until about 20 minutes after totality; the values observed during this period were about 20% lower than the mean derived from two equal periods immediately preceding and following it. *b.* During the period of potential-gradient minimum the fluctuations of the gradient were very much smaller than during the similar periods preceding and following. *c.* The positive and negative conductivities (and, therefore, the total conductivity also), each showed an increase of the order of 20%, beginning just after totality and continuing for about 15 minutes. *d.* The air-earth current density (product of simultaneous values of potential gradient and total conductivity) showed a greater constancy during the period in question than for any equal period throughout the forenoon of the day of the eclipse.

The results for May 29, 1919, at Sobral, are in general agreement with those obtained at Lakin, during the eclipse of June 8, 1918,[6] notwithstanding the great difference between the two stations as regards latitude, elevation, general topography, and distance from sea.

7. *Terrestrial Magnetism and Seismology:* Records of seismic disturbances are frequently obtained on magnetograms and thus arise problems of joint interest with the Section of Seismology. Prof. Reid has made a special study of these magnetograph records and finds that the oscillations

of the magnets producing the records are chiefly mechanical in their origin.[7]

8. *Terrestrial Magnetism and Electricity, and Physical Oceanography:* The problems of joint interest to the two sections relate to the magnetic and electric observations over the oceans, the delineation of disturbed regions, especially near ports, the effect of ocean depths on changes of the magnetic elements as observed over the surface, etc.

9. *Terrestrial Magnetism and Electricity, and Volcanology:* Besides local changes in the distribution of the earth's magnetic forces in the neighborhood of volcanic eruptions, there are other points of joint interest to students of volcanology and of terrestrial magnetism and electricity. As an illustration may be cited the remarkable circumstance of a world-wide magnetic disturbance which took place almost simultaneously over the entire earth, beginning at 7 h. 54 m. St. Pierre local mean time on May 8, 1902. According to the reports at the time of the Mont Pelée eruption the town clock at St. Pierre was found stopped at 7 h. 50 m.; how accurately this clock kept local mean time is, of course, not known and it may be that the time as obtained from the magnetic records will have to be regarded as the most accurate determination of the beginning of that remarkable eruption. Magnetic disturbances occurred again during the eruptions of May 20 and May 21, 1902.

At the meeting of the "Congress of Arts and Science," held at St. Louis, 1904, L. A. Bauer gave a preliminary discussion of the magnetic disturbances just referred to in connection with his paper on "The Present Problems of Terrestrial Magnetism."[8] The precise causal connection, if any, between the Mont Pelée eruption and the magnetic disturbance has not been completely worked out at present. The connection may have to be sought through the fact that there were remarkable electric phenomena during the eruption which may have caused a sufficient change in the electrification, or in the electric currents, of the earth's atmosphere to have produced in turn a magnetic effect.

During the eruption of Krakatoa, Java, of 1883, there was no world-wide magnetic disturbance. However, a local disturbance, of discontinuous character, occurred at the near-by Batavia Magnetic Observatory, this disturbance lasting merely during the rain of volcanic ashes upon Batavia, and the magnetic effect was attributed by the director of the Batavia Observatory to the magnetic character of the ashes. The electric phenomena in connection with the Krakatoa eruption were also very marked and changes of interest to students in terrestrial electricity may have occurred.

The question of electric currents in the earth's crust in connection with volcanic eruptions is also a matter of interest. Thus Palmieri[9] made earth-current observations in the vicinity of Vesuvius during the period 1889–1893. His observations seemed to show a parallelism with the

activity of the volcano. He furthermore found that the action of Vesuvius was such as to mask the diurnal variation in the observations of earth currents.

Reference may also be made to the investigations by Folgheraiter and others in Italy, B. Brunhes and P. David, in France, with regard to the magnetization of lava beds.

10. *Laboratory Problems in Terrestrial Magnetism and Electricity:* One of the prime purposes of the Section of Terrestrial Magnetism and Electricity should be to stimulate research in these fields as widely as possible so as to increase the number of workers, especially at our universities. About the middle of the last century very much of the investigational work in the United States in the subjects here considered was carried out by university professors. It must be one of our endeavors therefore to present and suggest problems which might be advantageously taken up at universities, either in connection with laboratory work or field investigations, over a region of greater or less extent.

Among some of the problems for experimental and theoretical investigation may be mentioned those with regard to the origin of the earth's magnetic field, origin and maintenance of the earth's electric field, improvement of instrumental appliances for magnetic and electrical measurements on the surface of the earth and at altitudes above, the effect of pressure upon the critical temperature of magnetization, studies in magnetism, in general, etc.

In conclusion, let it be stated that the incompleteness of this sketch of some of the chief problems of concern and interest to the Section of Terrestrial Magnetism and Electricity is fully realized. Other topics of importance could profitably have been dilated upon, especially with regard to the question of the origin of the earth's magnetic field and as regards certain outstanding problems in the fruitful subjects of atmospheric electricity, earth currents, polar lights, upper-air electric phenomena bearing upon radio-telegraphy, etc. It must suffice, owing to the limits imposed upon the present paper, merely to have called attention to these additional problems, and to reserve fuller treatment for a subsequent occasion. It is hoped, however, that enough has been said to show the intimate relation of the various problems not only to the sister branches of geophysics represented by the other sections of the American Geophysical Union, but also to the general subjects of physics, astronomy and geology.

[1] See *Terrestrial Magnetism and Atmospheric Electricity,* **9,** 1904 (127, 128).

[2] *Philosophical Magazine* for December, 1919 (669–684).

[3] *Proceedings Royal Society, A,* **95,** 1918 (61–83); also *Monthly Notices of R. A. S.,* Nov., 1918 (70–83); and *Observatory, London,* **42,** No. 539, May, 1919 (196–206).

[4] See L. A. Bauer's "Resumé of Observations Concerning the Solar Eclipse of May 29, 1919, and the Einstein Effect," *Science,* March 26, 1920 (201–311).

[5] See article by S. J. Mauchly and A. Thomson, *Terrestrial Magnetism and Atmospheric Electricity* for June, 1920.

[6] *Terrestrial Magnetism and Atmospheric Electricity,* **24,** June, 1919 (96).

[7] See *Terrestrial Magnetism and Atmospheric Electricity,* **19,** 1914 (57–72, 189–203); also *Bulletin of the Seismological Society of America,* **4,** 1914 (204–214).

[8] See *Publications of St. Louis Congress of Arts and Science,* **4,** 1904 (750–756).

[9] Palmieri, L., "Osservaziones delle correnti telluriche," *Rend. d'Acad. Napoli,* **3,** 1890 (225, 250); **4** (164, 228); **5** (216).

THE PROBLEMS AND FUNCTIONS OF THE SECTION OF PHYSICAL OCEANOGRAPHY OF THE AMERICAN GEOPHYSICAL UNION

BY G. W. LITTLEHALES

The former and present function of the ocean in the history of the earth and in its economy has forged bonds of kinship between oceanography and many other branches of science. Ever since the ocean became the world-encompassing highway of communication, its surface aspects, embracing the movements of the waters in waves, tides, and currents, have been subjects of observation. With the advance of the physical sciences and a knowledge of the extent of the ocean came the realization that so large an expanse of a substance having the highest known capacity for heat must, to a large extent, govern the external temperature of the earth and exercise an important influence as a factor in geophysics. But centuries of voyaging did not extend marine observations beyond the delineation of coasts and the service of navigation; and, in the middle of the nineteenth century, the sea remained unfathomed, and the observations of the physicist, the chemist, the geologist, and the biologist did not extend beyond the shallow coastal waters.

In setting forth the principal deep-sea expeditions, by nations and states, through the names of the vessels engaged and the period of their service, we shall serve ourselves the purpose of reflecting the progress of the attempts that have been made to ascertain the physical characteristics of that vast region of the earth's surface which is occupied by the deeper waters of the ocean:

Austria
  Pola (1891–1910).
Belgium
  Belgica (1897–9).
Denmark
  Ingolf (1895–6).
France
  Travailleur } (1880–3).
  Talisman }
  Caudan (1895).
  Français (1903–5).
Germany
  National (1889).
  Valdivia (1898–9).
  Gauss (1901–3).
  Planet (1906–14).
Great Britain
  Lightning (1868).
  Porcupine (1869–70).
  Challenger (1873–6).